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DIRECT UV OBSERVATIONS OF THE CIRCUMSTELLAR ENVELOPE OF α ORIONIS

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ABSTRACT

α Orionis is a red supergiant star with significant mass loss ($\sim 10^{-6} M_{\odot} yr^{-1}$). It is known from optical and infrared observations to possess an extended, arc-minute sized, shell of cool material. Attempts to observe this shell with the IUE are described, although the deconvolution of the stellar signal from the telescope scattered light will require further calibration effort.

Keywords. Circumstellar shell; Scattered light; Chromospheres, Ultraviolet Spectroscopy.

1. *INTRODUCTION*

There exists an arc-minute sized shell of luminous material surrounding the red supergiant, α Ori. It is observed in the light of the low abundance species, neutral potassium (at 7699Å - Honeycutt, et al. 1980), and in the far-infrared by *IRAS* (Stencel, Bauer and Pesce 1988). This fact suggested to us that it might be possible to observe scattered Mg II 2800Å photons over a comparable dimension, if the chromospheric ionization fraction is maintained in the outflow. Theoretical predictions of the ionization fraction in the outer atmosphere, by Glassgold and Huggins (1986), as well as direct measurement, using microwave techniques, (Drake and Linsky 1986; Drake et al. 1987), appear to support the expectation that there are numerous Mg ions scattered over large distances in the envelope of α Ori. IUE is well matched to an investigation of the outer envelope, given the 10 by 20 arc second apertures, which sample dimensions of roughly $6\times10^{16} cm (\sim 10^{3} R_{*})$ at the distance of α Ori

A series of observations were made in the LWP camera, low dispersion mode (IUE program CSJRS), with α Ori being offset various distances from the center of the Long Wavelength Large Aperture (LWLA), along its major axis. The longest exposure time was 480 minutes, with the star 30 arcseconds from the center of the LWLA. Derived signal levels are provided in Table 1. normalized to an IUE Flux Number (FN) per minute scale. The peak FN levels are in the center of the Mg II emission feature and in the nearby continuum, around 2825A. The reported temporal variations in the Mg II emission strength (cf. Dupree et al., this volume) were not considered in the present work Signal was acquired at all offset positions (Figures 1 and 2), and is comprised of unequal components of (1) background/dark counts, (2) telescope-scattered light and (3) scattered light emanating from the extended circumstellar shell of α Ori. The challenge is to successfully deconvolve these component signals and thereby reveal the intrinsic stellar signal, which can then be used to estimate the density, ionization and velocity field of the outer envelope.

2. SCATTERED LIGHT CORRECTIONS

In order to remove the detector background (dark count), we averaged the signal in part of the image, off the spectrum, near Mg II 2800A. We then subtracted this dark level from the data containing the spectrum data. The residual emission line signal [net FN per minute in Mg II] exhibits an approximate $d^{-2.1}$ falloff, for offsets (d) greater than 5 arcsec. The on-source exposure and the image with the LWLA centered 13" away (peak flux at 3" from the star), seem to lie along a steeper slope. Although signal in nearby continuum is weak, its falloff may be even slower If we use the inner 5 arcsec as a zero-order approximation to the telescope scattered light, it would appear that the signal at

10 and 20 arcsec from the star is relatively uncontaminated by scattered light. The ratios of brightnesses, compared to on-source values, are about 100 times that reported by Mauron et al. (1984) for K I 7699Å observations. However, there is no *a priori* justification for this kind of signal correction, and there is reasonable concern that the innermost data could be contaminated by the stellar image (3 arcsec FWHM).

The precise removal of telescope-scattered light from the residual signal is less straightforward. Unfortunately, there appears to be little surviving documentation of any pre-flight scattered light calibrations (e.g. Coleman et al. 1977). The original on-orbit empirical studies were made by Witt *et al.* (1982) who observed the early B dwarf star, η UMa at positions along the major axis of the LWLA and derived an approximate $d^{-3.3}$ falloff. We have re-examined their data and agree with their conclusion. In principle, this information could be used to remove the telescope- scattered light component from the residual signal, except for the following complications:

(a) Witt *et al.* reported scattered light levels in the **LWR** camera, not the **LWP** camera we used. The extra mirror feeding the LWR camera might be expected to increase the absolute magnitude of scattered light. DeBoer and Cassatella (1986) reported on measures of scattered light in the LWP camera, but unfortunately placed η UMa along the *minor* axis of the LWLA, which, as Carpenter *et al.* (1987) demonstrated, is heavily contaminated by a diffraction spike. It is unclear whether the slope is affected, but the magnitude of the scattered light could be enhanced. We argued that new LWP observations of η UMa along the major axis of the LWLA would be required, and three such observations were obtained during 1988 February [program OD38Y] as detailed in Table 2. The short time between receipt of the data tapes and this conference has not allowed for in-depth analysis of the new information. However, preliminary analysis suggests the magnitude of the scattered light for η UMa is slightly *greater* than that for α Ori, by 12 and 35% at 10 and 20 arcsec respectively. Given this tentative result, we conclude that the *blue* star, η UMa, may not be the most suitable object for establishing the level of telescope scattered light contribution around *red* stars like α Ori. Another problem with η UMa is that the on-source observations must be *trailed* to avoid overexposure. Parenthetically, we also note the non-symmetry in the *LWR* data obtained on opposite sides of the LWLA, at +20 and -20 arcsec. The peak signal strengths differ by a factor of 1.5, despite the virtually identical exposures. Given the slightly different optical path, the detailed mirror surface influence apparently is non-negligible.

(b) Unfortunately, at the time of this writing, there are no data which would allow us to assess the significance of stellar effective temperature as it relates to the intensity of telescope scattered light. α Ori is a red supergiant with a color temperature of about 3500K, while η UMa is a B dwarf with a color temperature of about 20,000K. Significant scattered light has been observed shortward of Ly-α (1215A) in the SWP camera when observing F type stars, although no analogous light has been seen shortward of C II] 2325A even in deep LWR or LWP camera observations of red stars. To investigate the magnitude of this effect, we propose that off-source observations of bright late-type main sequence stars, with negligible mass loss [e.g. ϵ Eri] should be undertaken. Our eleventh year IUE program, CMKRS, will pursue this.

3. DISCUSSION

Despite the present ambiguity regarding the correction for scattered light, we can still examine the implications of detection of Mg II light far from the star. Various authors have derived mass loss rates for α Ori, typically around $10^{-6} M_{\odot} yr^{-1}$. With the observed circumstellar shell expansion of approximately 15 km/sec, this implies a matter density of $\sim 10^{1} cm^{-3}$ at 10^{3} radii. From this, we could estimate an intrinsic efficiency for scattering of 2800A photons by Mg ions, subject to uncertain assumptions about the degree of ionization in the outer envelope. Calculations of the brightness distributions of resonant line photons have been made by Natta and Beckwith (1986) but their results are restricted to Sobolev regimes which cannot be applied to the Mg II line transfer problem in cool supergiants, namely, low optical depths and generally higher ratios of flow speed to microturbulence than are present in the expanding chromosphere of α Ori. Judge intends to begin calculations which remove the Natta and Beckwith [N&B] restriction to $a\tau_o$ much less than 1 (where a is the Voigt parameter), and to include "diffusive" transfer in the line wings (e.g. Basri 1979) which inhibit the direct escape processes as in N&B's calculations. This will enhance the intensity of photons further out in the circumstellar shell relative to the N&B results. Drake (1985) found a large effective angular diameter in Mg II 2800A for α Boo using this approach.

A more complete analysis of these data is being prepared for publication elsewhere. We are pleased to acknowledge the support of NASA grant NAG5-816 to the University of Colorado, as well as the outstanding help of the Resident Astronomers and Telescope Operators at both the Goddard and Vilspa ground station SOCs. We also thank James Neff for software assistance, Susan Conat Stencel for editorial improvements of the text, and acknowledge the Boulder RDAF (NAS5-28731) for its helpful facilitation of this work

4. REFERENCES

Basri, G. 1979 *Astrophys. J.* **230**, 924.

Beckwith, S. and Natta, A. 1987 *Astron. Astrophys* **181**, 57.

Carpenter, K., Stencel, R., Pesce, J., Brown, A. and Judge, P. 1987 *IUE NASA Newsletter* **33**, p. 20.

Coleman, C. *et al.* 1977 "IUE Camera Users' Guide" - IUE Tech. Note 31, UCL/Rutherford Appleton Lab, cited in NASA IUE Newsletter 32 (1987).

DeBoer, K. and Cassatella, A. 1986 *New Insights into Astrophysics* ESA Spec. Publ. 263, p. 665.

Drake, S. 1985 in *Progress in Stellar Spectral Line Formation and Theory*, eds. J. Beckman and L. Crivellari (Dordrecht; Reidel).

Drake, S. and Linsky, J. 1986 *Astron. J.* **91**, 602.

Drake, S., Linsky, J. and Elitzur, M 1987 *Astron J.* **94**, 1280.

Glassgold, A. and Huggins, P. 1986 *Ap.J.* **306**, 605.

Honeycutt, R., Bernat, A., Kephart, J., Gow, C., Sandford, M. and Lambert, D. 1980 *Ap.J.* **239**, 565.

Mauron, N., Fort, B., Querci, F., Dreux, M , Fauconnier, T. and Lamy, P. 1984 *Astron. Astrophys* **130**, 341

Natta, A. and Beckwith, S. 1986 *Astron. Astrophys.* **158**, 310.

Stencel, R., Bauer, W. and Pesce, J. 1988 *A J* **95** 141.

Witt, A., Walker, G., Bohlin, R. and Stecher, T. 1982 *Ap J* **261**, 492.

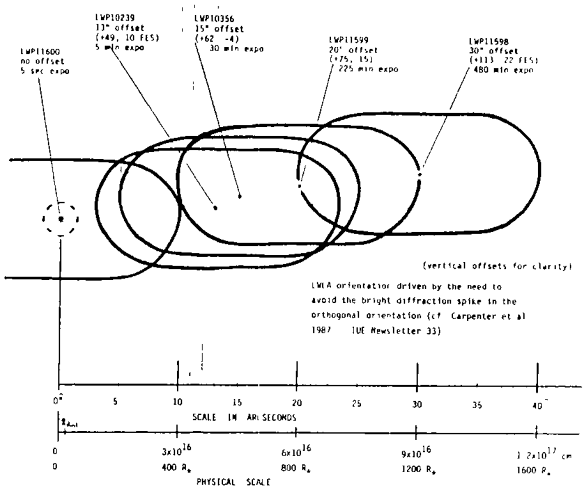

Figure 1: Positions of the LWLA with respect to α Ori, for the new LWP observations reported here (Table 1).

Table 1
α Ori IUE Data Used, programs CSJRS and OD14Y

Image	Offset arcsec	Exposure	Peak FN	Bkgd FN	Log Net FN/min (in Mg II)	Log Net FN/min (nearby cont)
LWP11600	0"	5 sec.	8,224	~ 0	4.99 (0 00)	4 08 (0 00)
LWP10239	+13"	5 min.	5,519	~ 0	3.04 (-1 95)	2 23 (-1 85)
LWP10356	+15"	30 min	6,830	1,850	2 22 (-2.77)	1 56 (2 52)
LWP11599	+20"	225 min.	12,796	2,475	1.66 (-3 33)	1.00 (-3.08)
LWP11598	+30"	480 min	8,032	3,328	0.99 (-4 00)	0 39 (-3.69)

Note: Offset is to center of LWLA, while peak signal occurs in the aperture at the position closest to the star, generally 10" from the nominal offset The Log Net FN/min in parentheses are relative to the on–source value. Preliminary values

Table 2
η UMa IUE Data Used, programs PHCAL and OD38Y

Image	Offset arcsec	Exposure	Peak FN	Bkgd FN	Log Net FN/min [near 2800A]
LWR2127	0"	0.29 sec,T	34,100	~ 0.	7.36 (0 00)
LWR6576	+ 12.5	5 sec	61,524	~ 0.	5 57 (-1.79)
LWR6575	+ 15"	25 sec	57,000	~ 0	5 14 (-2 22)
LWR6579	+ 18"	22 sec	6,172	~ 0	4 22 (-3 14)
LWR6574	+ 20"	68 sec	17,146	~ 0	4 17 (-3.19)
LWR6577	-20"	67 sec	10,810	~ 0.	3.99 (3 37)
LWR6578	-40"	271 sec	4,856	771	2 96 (-4.40)
LWP 9700	0"	0.19 sec,T	7,556	~ 0.	6.85 (0.00)
LWP12653	+ 20"	45 sec	2,827	~ 0.	3.58 (-3.27)
LWP12652	+ 30"	60 sec	949	~ 0.	2.98 (-3.87)
LWP12654	+ 30"	300 sec	5,048	258.	2 98 (-3 87)

Note: offset is to center of LWLA, while peak signal occurs in the aperture at the position closest to the star, generally 10" from the nominal offset. The T next to the exposure time indicates a trailed exposure, where the effective exposure is 3.7 times the pointed exposure. No corrections for camera senstivity changes have been made The Log Net FN/minute numbers in parentheses are relative to the on–source value. Preliminary values.

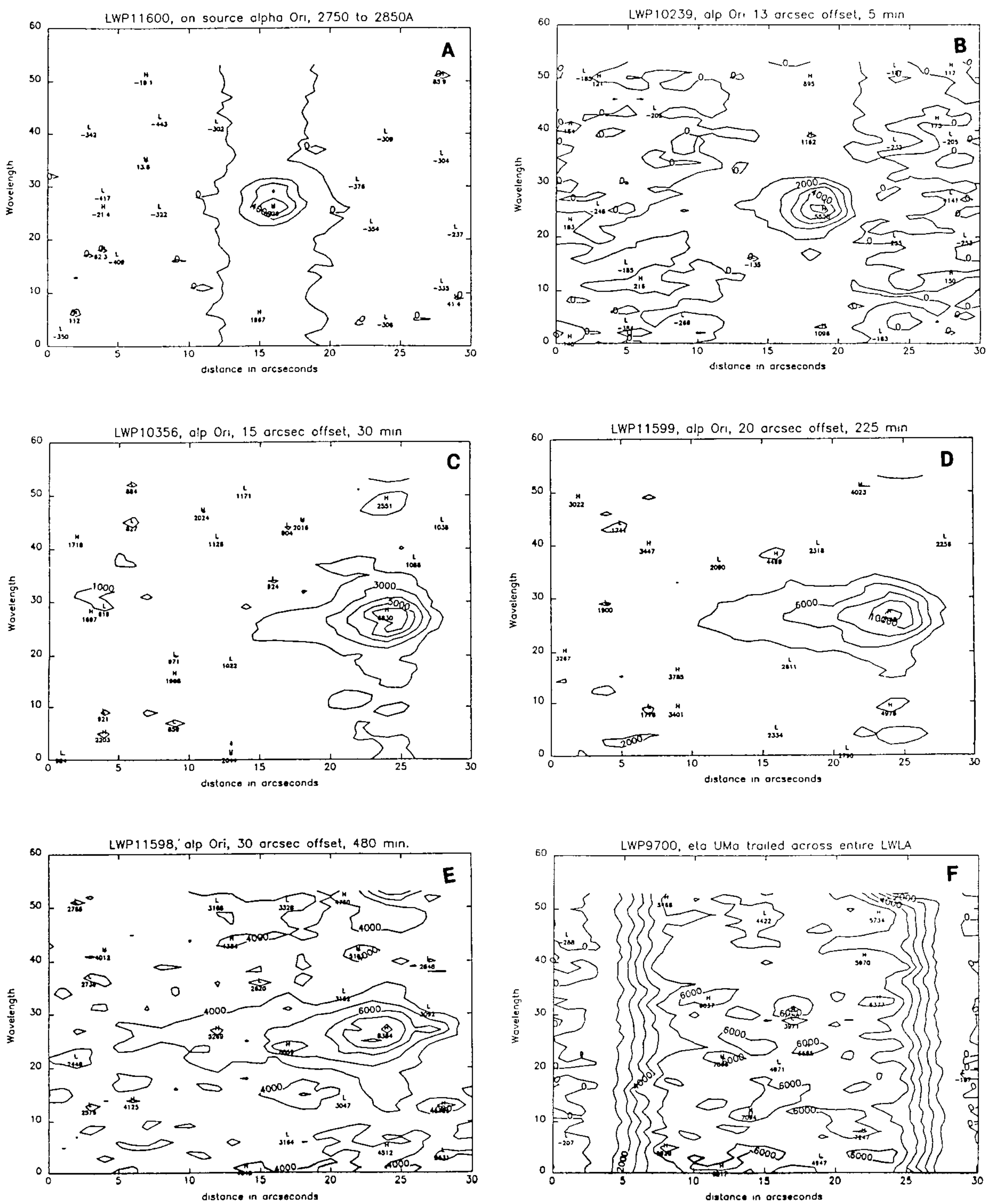

Figure 2: Montage of contour maps of spectral images of α Ori, near Mg II at varying offset distances. The images are: (a) LWP 11600; (b) LWP 10239; (c) LWP 10356; (d) LWP 11599; (e) LWP 11598, and (f) LWP 9700 (η UMa, on-source, trailed exposure illuminating entire LWLA, for scale). See Tables 1 and 2 for characteristics of each. Each frame plots a spatial dimension (abscissa, 30 arcseconds full range) versus a spectral dimension (2750 to 2850A). Note the gradient in the signal toward the edge of the LWLA, in the direction of the star (off to the right). Local maxima and minima at marked, units are FN.